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16. ABSTRACT

The U.S. Environmental Protection Agency has undertaken the development of a series of reports identifying specific deficiencies in the design of wastewater treatment facilities and presenting corrective solutions to avoid the error or to solve the problem. This report describes problems that are associated with organic overloading of Rotating Biological Contactor (RBC) units, presents an analysis of field data from RBC treatment plants identified as experiencing problems associated with organic overloading, and suggests design concerns that should be recognized in order to avoid RBC organic overloading and its associated process performance and equipment problems. Any one of a range of organic loading values for design may be used, the magnitude of which depends upon the risk of failure that the designer is willing to assume.

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EPA Design Information Report

The U. S. Environmental Protection Agency has undertaken a program to help municipalities and engineers avoid problems in wastewater treatment facility design. A series of documents will be produced that identify frequently occurring process design problems and describe remedial measures and design approaches used to solve these problems. The intent is not to establish new design practices, but to concisely document improved design procedures that have been developed from field experiences. Readers are encouraged to use the *Journal's* discussion section to contribute additional information or views on these topics.

Consideration of first-stage organic overloading in rotating biological contactor design

Francis L. Evans III

Rotating biological contactor (RBC) units can be an effective wastewater treatment process to remove organic material, as measured by the 5-day biochemical oxygen demand (BOD_5) test. The basic RBC unit (module) consists of an 8.23-m (27-ft) shaft, to which is attached 7.62 m (25 ft) of 3.66-m (12-ft) diameter media disks that are partially submerged in the wastewater flow. An RBC module may be constructed with either a single shaft or multiple shafts contained in a single tank. Staging, the segregation of media groups within the same tank, is accomplished by placing submerged baffles or bulkheads either perpendicular to the shaft in a single shaft tank or parallel to the shafts in a multi-shaft tank.

The configurations of RBC systems may increase in complexity from a single module of one media-support shaft to one or more trains of multiple shaft modules in various combinations of series or parallel flow. The media surface area required to achieve desired process efficiency dictates the site-specific modular and staging arrangement. As few as one RBC unit of one or more stages may be sufficient for less stringent treatment requirements; additional modules, of one or more stages, may be used to produce a higher quality effluent and to achieve nitrification.

Because process staging inherently results in plug-flow hydrodynamics, biochemical oxygen demand (BOD) removal through the process train reflects the configuration of a series of plug-flow reactors. The BOD is removed by increments, and the BOD loading decreases as wastewater flows through successive stages. Thus, organic loading to each stage differs according to its position in the train, with the initial stage receiving a much higher loading than the latter stages. This also causes different species of a microbiological population to form on the media, reflecting the organic loading specific to each stage.

PROBLEM DESCRIPTION

Technical literature and empirical observations[1,2] describe typical biomass on RBC media as a golden-brown shaggy mass, with the heaviest biological growths occurring in the initial stages where the organic loading is highest. Microscopic examination of a healthy mass in a well-operating facility shows good bacterial floc, numerous free-swimming ciliates, stalked ciliates and, in the latter stages, rotifers and nematodes. However, when the first stage is permitted to operate with continued high organic loading, the film thickness increases and a white-grey biomass covers substantial portions (for example, 40%) of the media surface. This condition suggests that nuisance organisms, which appear microscopically as stringy, grey-black hair-like bacterial or fungi filaments, are present. RBC units that operate under this set of conditions are described as organically overloaded. Continued operation in this mode may cause process perfor-

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mance to deteriorate, depending on the extent of nuisance organism proliferation and the extent of media coverage.

Organic overloading is characterized, therefore, by the growth of an excessively thick biological film on the media surface and may be accompanied by or result in one or more of the following process performance and operational problems.

- There is a deficit of dissolved oxygen in the bulk liquid.
- Oxygen transfer from bulk liquid and air is hindered to inner film layers on the RBC disks.
- Anaerobic conditions within the biofilm cause undesirable microorganism species (such as sulfur-oxidizing bacteria, for example, *Beggiatoa*, and other filamentous organisms) to dominate on the media.
- Microaerophiles develop and predominate throughout the biofilm and reduced BOD removal is attributed to their lower metabolic rates.
- Septic odors develop from both the bulk liquid and the biofilm.
- Bridging occurs between the contactor plates, subsequently clogging the media and effectively reducing media and biofilm surface area and hindering oxygen and substrate transport.
- The ability to control biofilm sloughing and film thickness by liquid shearing forces is eliminated.
- Energy requirements are increased.
- Unbalanced structural loading, structural overloading, and structural failure of the media support framework and central shaft occur.

In addition to these process performance and operation problems, first-stage organic overloading can significantly increase the labor and cost requirements for maintenance activities including inspection, lubrication, and general housekeeping. The greater operation and maintenance (O&M) requirements and costs derive from the following:

- Increased operator time required to counteract excessive biomass growth, eliminate odors, and improve system performance;
- Increased analytical requirements to determine the extent of the problem and to formulate corrective measures;
- Increased energy requirements for supplemental aeration to reverse oxygen deficiency conditions; and
- Increased time and, possibly, costs to improve solids settling in the final clarifier.

In the extreme case, it can be very expensive if one unit must be removed from service and the media, media support frame, or shaft must be repaired or replaced.

AVAILABLE FIRST-STAGE ORGANIC OVERLOADING DATA

Treatment plant data used in this research were derived from a recent study of RBC facilities conducted for the U. S. Environmental Protection Agency (EPA).[1] The purpose of that survey was to review design procedures and compare design specifications with empirical performance data. Candidate plants that treated primarily domestic waste, operated at 80% or more of the design flow, and regularly monitored influent and effluent quality were selected for the study. Package plants, which represent 25% of RBC municipal facilities nationwide, were not considered. Only 16 facilities were chosen for analysis, a representation of the limited number approaching selection criteria goals. Eight additional facilities, which were reported to have been experiencing problems attributed to organic overloading but did not otherwise meet the stated selection criteria, were also included. In this latter group, an overloaded environment was identified by the characteristic takeover by nuisance organisms that proliferate under oxygen deficiency conditions. Data were compiled from all 24 plants through site visits, monitoring reports submitted by plant personnel to the respective state agency, and information obtained directly from plant operators.

Data that pertained to the RBC plants studied are shown in Table 1. These data include: design and actual plant flow; first stage(s) and total plant media surface area; total BOD_5 concentration in the RBC influent and in the clarifier effluent before chlorination; and organic loadings to the first stage(s) and to the total RBC system combined. Table 2 shows additional plant data including a notation of those plants which did or did not experience first-stage overloading.

The BOD_5 values in Table 1 reflect both actual data available and estimations when specific data were not available. When it was necessary to calculate the first-stage influent BOD_5 concentration, an initial 25% BOD_5 removal of the raw wastewater concentration was assumed when primary clarifiers were in use, and zero BOD_5 removal was assumed when screens or sieves were used as primary units.

First-stage effluent BOD_5 concentration data were generally not available; therefore, the values in the table or used in calculations and analyses are those reported for the secondary clarifier effluent before chlorination. The organic loading values are calculated from actual flow and RBC influent BOD_5 concentrations. Finally, the total media surface area or the first-stage surface area, as defined by the process configuration, is used in the calculation of the total RBC process or first stage(s) organic loading, respectively.

Figure 1 shows an array of the calculated first-stage organic loading values in increasing magnitude to illustrate the relationship between organic loading and the incidence of problems associated with first-stage overloading. At first stage loadings up to 17.6 g $BOD_5/m^2 \cdot d$ (3.6 lbs BOD_5/day/1000 sq ft) there were no overloading problems; nonetheless, problems were always reported when the first-stage loading was greater than 43.0 g $BOD_5/m^2 \cdot d$ (8.8 lbs BOD_5/day/1000 sq ft). Forty-two percent of the surveyed facilities fell within this loading range. Some of these plants experienced problems associated with organic overloading and some did not. While an explanation is not available at this time, the differences may be attributed to factors such as variations in influent waste characteristics, temperature, specific tank design, specific media configuration, shaft rotational speed, and fluid turbulence.

PROCESS DESIGN CONSIDERATIONS

Details of current RBC process design practices are available from other sources[2,7] and are not repeated here. It should be reiterated, however, that the required total media surface area and first-stage media surface area, and the number of stages for each specific installation, are primarily determined by the design flow, influent waste strength in terms of soluble or total BOD_5, and the required effluent quality.

Standard density RBC units with 9.3×10^3 m^2 (100 000 sq ft) of media surface area are used in the initial stage(s) to remove

Table 1—RBC plant-specific design and performance data.

Plant ID number	Average flow, mL/d (mgd)		Media surface area, 10^3 m² (1000 sq ft)		Average total BOD_5, mg/L		Organic loading g/m²·d (lbs/day/1000 sq ft)	
	Design	Actual	1st stage	Plant total	First stage influent[a]	Plant effluent[b]	1st stage	Overall
29	102.2 (27.0)[c]	98.0 (25.9)	130.1 (1400)	520.2 (5600)	93	32	70.3 (14.4)	17.6 (3.6)
31	5.7 (1.5)	1.9 (0.5)	7.4 (80)	29.7 (320)	145	NA	37.1 (7.6)	9.3 (1.9)
5	1.9 (0.5)	1.8 (0.5)	5.8 (62)	23.0 (248)	150	23	46.9 (9.6)	11.7 (2.4)
33	2.5 (0.7)	1.5 (0.4)	9.3 (100)	37.2 (400)	350	NA	55.2 (11.3)	13.7 (2.8)
34	22.7 (6.0)	15.0 (4.0)	57.6 (620)	426.6 (4592)	94	16	24.4 (5.0)	3.4 (0.7)
36	11.4 (3.0)	5.1 (1.4)	19.1 (206)	76.7 (826)	212[e]	16	56.6 (11.6)	14.2 (2.9)
10	1.9 (0.5)	2.1 (0.6)	7.4 (80)	29.7 (320)	175[f]	28	49.8 (10.2)	12.7 (2.6)
32	0.8 (0.2)	0.6 (0.2)	7.4 (80)	14.9 (160)	505[e]	NA	39.5 (8.1)	19.5 (4.0)
15	10.6 (2.8)	6.7 (1.8)	27.9 (300)[d]	111.5 (1200)[d]	167	13	60.0 (12.3)	15.1 (3.1)
30	18.9 (5.0)	8.3 (2.2)	35.5 (382)	117.3 (1908)	175	NA	41.0 (8.4)	8.3 (1.7)
12	6.6 (1.8)	5.2 (1.4)	7.1 (76)	28.3 (305)	80[g]	27	58.6 (12.0)	14.6 (3.0)
1	7.2 (1.9)	7.8 (2.1)	18.6 (200)	102.2 (1100)	145[e]	12	60.5 (12.5)	11.2 (2.3)
7	4.9 (1.3)	4.5 (1.2)	35.7 (384)	107.0 (1152)	228[e]	26[h]	28.8 (5.9)	9.8 (2.0)
11	2.3 (0.6)	2.0 (0.5)	4.2 (45)	16.7 (180)	82	28	39.1 (8.0)	9.8 (2.0)
9	3.8 (1.0)	3.8 (0.8)	9.3 (100)	37.2 (400)	144[e]	27	45.9 (9.4)	11.7 (2.4)
35	2.1 (0.6)	0.7 (0.2)	3.2 (34.2)	12.7 (137)	175[f]	20	51.3 (10.5)	12.7 (2.6)
3	2.1 (0.6)	1.9 (0.5)	4.1 (44)	16.4 (176)	91[f]	28	43.0 (8.8)	10.7 (2.2)
14	7.6 (2.0)	5.0 (1.3)	18.6 (200)[c]	74.3 (800)[c]	71	23	38.1 (7.6)	9.3 (1.9)
13	3.8 (1.0)	2.5 (0.7)	16.4 (176)	49.1 (528)	80	10	12.2 (2.5)	3.9 (0.8)
16	1.3 (0.4)	1.3 (0.3)	4.5 (48)	17.8 (192)	61	25	17.6 (3.6)	4.4 (0.9)
8	1.5 (0.4)	2.0 (0.5)	3.2 (34)	12.7 (137)	52[f]	21	32.7 (6.7)	8.3 (1.7)
2	4.9 (1.3)	4.2 (1.1)	27.9 (300)	55.7 (600)	69[f]	17	14.6 (3.0)	7.3 (1.5)
4	0.8 (0.2)	0.3 (0.1)	4.0 (42.5)	15.8 (170)	71[f]	12[i]	4.9 (1.0)	1.2 (0.2)
6	1.1 (0.3)	0.9 (0.3)	4.9 (52.5)	19.5 (210)	152	9	29.3 (6.0)	7.3 (1.5)

[a] Actual value unless otherwise noted.
[b] Clarified secondary prior to chlorination unless otherwise noted.
[c] Permit design capacity as of 1978.
[d] As installed. Only two-thirds of the design capacity in use during study period.
[e] Primary removal of BOD_5 by hydrosieve screens assumed to be negligible or replaced by sidestream return flows.
[f] Primary removal of BOD_5 by primary clarifiers assumed to be 25% including effect of sidestream return flows.
[g] Estimated value after treatment by primary clarifier and trickling filter.
[h] Effluent from gravity filters.
[i] Effluent from sand filters.

carbonaceous organic matter. However, when subsequent stages are necessary to achieve a higher effluent quality, high density units with 13.9×10^3 m² (150 000 sq ft) of media surface area can generally be used because the potential for excessive biomass growth and media clogging is diminished. An exception to this generality may occur when the RBC shaft is air-driven or supplemental aeration is used in certain applications.

Figure 1 suggests that problems associated with organic overloading in the first stage frequently occur at or above BOD_5 loading of 17.6 g/m²·d (3.6 lbs/day/1000 sq ft) and will always occur at loadings greater than 43.0 g/m²·d (8.8 lbs/day/1000 sq ft). The use of either one of these extreme values, or any mid-range loading value, for design purposes does not guarantee that the operating facility will be free from overloading problems. The design intent and use of a rational loading value in determining the first-stage media surface area requirements should be to minimize the probability of organic overloading in the first stage and to maximize the reliability of latter stage process performance and plant effluent quality.

First-stage organic loading data were subjected to a discriminant analysis.[8] This statistical tool is a classification function developed from a regression analysis that minimizes the probability of misclassifying specimens (RBC plants) into those having problems or those not having problems. Based on the statistics developed in this analysis, a curve, which shows for a range of organic loading values the probability that the plant would or would not develop or experience first-stage organic overloading problems was constructed (Figure 2). For example, the curve indicates that at a total BOD_5 loading of 35.6 g/m²·d (7.3 lbs/day/1000 sq ft), there is a 50% chance (0.5 probability) that the first-stage unit will become overloaded and that one or more units will experience organic overloading problems. Similar probability estimates may be made for soluble BOD_5 loadings, by either using empirical soluble organic data or estimating the soluble fraction to be 40 to 60% of total BOD_5 in the RBC influent.

The discriminant analysis described and the values used to develop the probability curve are unique to the specific data set (specific RBC facilities) selected for study. The use of a different or larger data set and a different statistical tool may result in a different graphical plot that justifies the use of other loading values for design. In addition, factors that affect process perfor-

Table 2—RBC survey plant identification data.

	Plant ID number	Plant location	Number of shafts: First stage	Number of shafts: Total plant	Data collection period
Plants exhibiting first-stage organic overloading problems	29	Alexandria, Va.	14	56	Feb. '78–Dec. '78
	31	Benton, Ark.[4]	1	4	N/A
	5	Edgewater, N. J.[3]	1	4	Jan. '76–Feb. '79
	33	Ellsworth, Wis.	1	4	N/A
	34	Fort Knox, Ky.[5]	6	36	Jan. '78–July '79
	36	Georgetown, Ky.[5]	2	8	July '78–June '79
	10	Gloucester, N. J.	1	4	July '75–June '76
	32	Hopkinton, Iowa	2	4	July '80–July '81
	15	Ionia, Mich.	3	12	Jan. '79–Aug. '79
	30	Kirksville, Mo.	4	20	N/A
	12	North Huntington, Pa.[6]	1	4	Sept. '78–Sept. '79
	1	Rhinelander, Wis.[5]	2	10	July '78–July '79
	7	Selden, N. Y.	4	12	Jan. '79–Aug. '79
	11	Thermopolis, Wyo.	2 @ 1/4[a]	2	Nov. '78–Nov. '79
	9	Winchester, Ky.	1	4	July '78–July '79
	35	Woodland, Wash.[5]	2	2	Jan. '78–June '79
Plants not exhibiting first-stage organic overloading problems	3	Battleground, Wash.	2 @ 1/4[a]	2	July '78–Aug. '79
	14	Cheboygan, Mich.	2	8	Dec. '78–Sept. '79
	13	Gladstone, Mich.	2	6	Jan. '78–July '79
	16	Hartford, Mich.	1 @ 1/2[b]	2	Feb. '79–June '79
	8	Niagara, Wis.	2 @ 1/4[a]	2	Mar. '78–July '79
	2	Toppenish, Wash.	3	6	Oct. '73–Sept. '79
	4	Wappingers Falls, N. Y.	2 @ 1/4[a]	2	Jan. '73–Dec. '78
	6	Washington Twp., N. J.	3 @ 1/4[a]	3	Jan. '78–Apr. '80

[a] Each shaft baffled to produce four stages per shaft.
[b] Each shaft baffled to produce two stages per shaft.

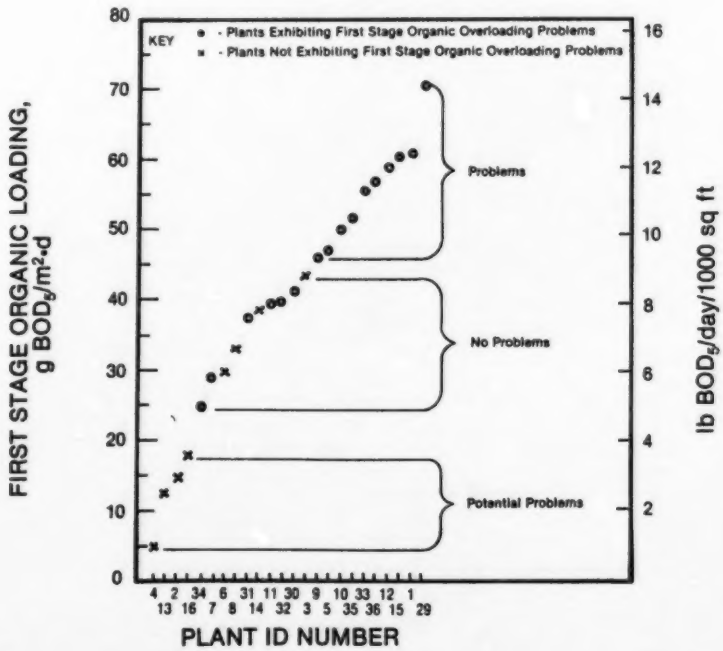
KEY
• - Plants Exhibiting First Stage Organic Overloading Problems
x - Plants Not Exhibiting First Stage Organic Overloading Problems
Problems
No Problems
Potential Problems
FIRST STAGE ORGANIC LOADING, g BOD5/m2·d
lb BOD5/day/1000 sq ft
PLANT ID NUMBER
4 2 34 6 31 11 30 9 10 33 12 1
13 16 7 8 14 32 3 5 35 36 15 29

Figure 1—Array of first-stage organic loading data.

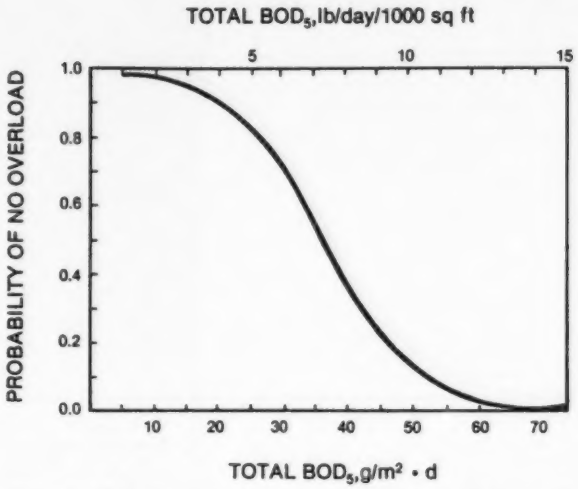

Figure 2—Probability-based first-stage organic loading values for design.

mance, such as those that are nonquantifiable and variable from site to site, may be the dominant concern. Therefore, the use of one particular loading value does not guarantee the occurrence of or freedom from overloading problems. The higher the loading value used, the greater the probability that first-stage overloading problems will develop.

The RBC total plant media surface area may be designed with conservative loading values and overloading problems may not be experienced in latter stages; however, first-stage overloading and concomitant deterioration of first-stage effluent quality is not a concern that is dismissed easily or a problem that corrects itself. On the contrary, the lower quality influent to down-train RBC units can progressively disrupt the performance of subsequent stages, decreasing treatment efficiency and eventually resulting in the deterioration of effluent quality and overall plant noncompliance. As previously described, other problems associated with organic overloading will also be experienced. Therefore, the design of RBC media total surface area should accommodate the constraint of avoiding organic overloading. The standard for good design practice results not only in achievement of site-specific effluent quality standards but also to prevention overloading in any and all stages. A rational design approach includes proper staging considerations and first-stage loading constraints.

DESIGN CONSIDERATIONS

The following design concerns should be addressed to minimize organic overloading in the first stage of an RBC treatment process and to avoid problems associated with first-stage overloading:

- The risk of developing first-stage organic overloading problems increases with increased first-stage design organic loading. The design value to use is a function of the problem-occurrence probability and associated risk of poor performance to be assumed by the designers.
- For the total plant, all stages must be designed to operate within the same maximum first-stage load limits selected, and the loading should be reviewed on a stage-by-stage basis.
- Operational flexibility should accommodate variable hydraulic flow paths and organic loading configurations. As a minimum, controlled flow to multiple first stages should be provided and alternative flow and staging arrangements are desirable. Other flexibility options include: removable baffles between all stages; provisions for step feed; positive control of hydraulic flow to each train and unit; and air flow metering and positive control to each shaft when supplemental aeration or air drive units are used.
- The ability to vary the shaft rotational speed to increase operational flexibility and process control should be provided.
- Dissolved oxygen measuring instrumentation and load cells should be provided in the first stage as a minimum. As operating tools, these instruments will signal an impending bulk liquid oxygen deficiency or shaft overstress, or both.
- A system for supplemental aeration of the first stage and subsequent stages could be provided to increase bulk fluid dissolved oxygen levels, improve oxygen transfer capabilities, or regulate media biomass accumulations.
- When there are significant concentrations of sulfide in the raw wastewater, pre-aeration or prechlorination should be provided to reduce the oxygen demand and prevent the growth of sulfide-oxidizing organisms.

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